

**UNITED STATES PATENT APPLICATION**

of

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**and**

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for

**TWO-WIRE INTERFACE HAVING  
EMBEDDED PER FRAME RELIABILITY INFORMATION**

## BACKGROUND OF THE INVENTION

### **1. The Field of the Invention**

[0001] This application claims the benefit of United States Provisional Application No. 60/529,918 filed December 15, 2003, which is incorporated herein by reference in its entirety.

### **2. Cross-Reference to Related Applications**

[0002] The present invention relates generally to mechanisms for two or more components to communicate using a two-wire interface. More specifically, the present invention relates to a two-wire interface having embedded per-frame reliability information for reliable communication between the two components.

### **3. Background and Relevant Art**

[0003] Electronic and computing technology has transformed the way that we work and play. Many electronic or computing systems rely on a variety of components that cooperatively interact to perform complex functions. Such cooperative interaction often relies on the ability of the various components to communicate effectively.

[0004] There are many ways that electronic components may communicate. However, oftentimes a two-wire interface is used to communicate between components. Although communication using a two-wire interface can be slower than communication over other interfaces, the use of two-wire interfaces is preferred in some implementations because such interfaces often require less chip or board space between components. In addition, two-wire

interfaces often introduce less electromagnetic interference in the rest of the chip and/or board than many parallel interfaces.

[0005] In some conventional two-wire interfaces, one wire is used to carry a clock signal, and one wire is used to carry a data signal. The clock signal is generally generated by a master component and is used by the master component as well as by one or more slave components. Either the master component or a slave component may drive data onto the data wire following the timing of the shared clock signal. Each communicating component understands a common two-wire protocol used to communicate, and thus may each function appropriately given the data. The data line for two-wire interfaces typically includes not only data, but also a header field that identifies the operations to be performed (i.e., the operation code), the device identifier (in cases in which there may be multiple slave components to communicate with), and an address from which the data should be read or to which the data should be written.

[0006] One example of a prolific two-wire interface is the I<sup>2</sup>C interface. The I<sup>2</sup>C interface may be used to transfer large amounts (e.g., kilobytes or megabytes) of data using a single corresponding header field. In other words, the header field is provided once, and the corresponding operation is understood to correspond to all of the data to follow. Since the header field is provided only once for large amounts of data, the I<sup>2</sup>C interface is very efficient when communicating large amounts of data to and from memory.

[0007] Another kind of two-wire interface includes a header field for each byte or word of data being transferred. Such two-wire interface will be referred to as a “guaranteed header two-wire interface” since each byte or word or other small fixed amount of data is guaranteed to have its own header field identifying the operation to be performed. Since each byte or word of data has its own header field, there is significantly more bandwidth

used per unit of data transferred. Most often, in fact, there are more bits transferred that represent header information than there are that represent actual data to be read or written when using such guaranteed header interfaces. Accordingly, guaranteed header two-wire interfaces are not typically used for reading or writing large amounts of contiguous data. Instead, guaranteed header two wire interfaces are most often used for intermittently transferring small amounts of data as when, for example, occasionally setting configuration register values.

[0008] A frame of one conventional guaranteed header two-wire interface is illustrated in Figure 7 and is often referred to as the “MDIO” interface. In this description and in the claims, a “frame” of a guaranteed header two-wire interface is defined as that the structural information used to transfer the corresponding one byte or word of data.

[0009] The master component begins the frame by affirmatively asserting a preamble on the data wire. The preamble includes 32 bits, each having a logical one (corresponding to bits 64:33). This preamble gives an indication to each of the one or more slave components that the other header information and data is about to be transmitted.

[0010] The master component then transmits the next two bits (corresponding to bits 32:31) have a logical zero to represent the start of the frame. This conveys that the more meaningful data is about to be transmitted.

[0011] In particular, after the start of frame bits, the master component transmits the operation code (corresponding to bits 30:29). Under the MDIO standard, an address operation corresponds to operation bit values of 00, a write operation corresponds to operation bit values of 01, a read operation corresponds to operation bit values of 11, and a read increment operation corresponds to operation bit values of 10.

[0012] The master component then transmits the port address (corresponding to bits 28:24). This identifies the slave port that is to be communicated with. Under the MDIO standard, more than one slave component may correspond to a single port. Accordingly, to uniquely identify the slave component to be communicated with, the master component then transmits a device identifier (corresponding to bits 23:19), to thereby allow that slave component to get ready to receive further information in the frame. This also allows any other slave components that are not to be communicated with to ignore the rest of the frame.

[0013] The next two clock cycles (corresponding to bits 18:17) are used to switch which component is asserting bits on the data wire. If the operation is an address or a write operation, the master component first transmits a logical one followed by a logical zero. If the operation is a read or a read increment operation, on the other hand, the master component lets the data wire float with a high impedance. This provides a transition cycle for the master component to release control of the data wire, and allows the slave component to drive the data wire with a logical zero in the following cycle thereby allowing the slave component to acquire control of the data wire.

[0014] If the operation is an address operation, the master component then indicates the address (corresponding to bits 16:01) that is to be operated on in a subsequent operation. If the operation is a write operation, the master component then writes the data (corresponding to bits 16:01) to an address specified in a previous address operation. If the operation is a read operation, the slave component then places the read data (corresponding to bits 16:01) from the previously specified address on the data wire. If the operation is a read increment operation, the slave component places the read data (corresponding to bits 16:01) for the next contiguous address on the data wire.

[0015] Regardless of the component is in control of the data wire, the component then lets the data wire float (corresponding to bit 00). This completes the frame.

[0016] The MDIO interface is effective in transferring data for the most part. However, there is provided no space for reliability data to be included, other than in the data field itself. Furthermore, for an address operation, reliability information cannot be included even in the data field. For example, there is no cyclic redundancy checking information or acknowledgements of successful operation. Accordingly, if there is a deficiency in the communication, or implementation of the operation, the master component may never be informed of the same, and thus may continue operating on the mistaken assumption that the operation has completed. Alternatively, the reliability information may be included as part of the data. However, the use of that reliability information would require a layer of logic that recognized the data as reliability information. This would also reduce the space available for the core data of interest that is unrelated to reliability information.

[0017] What would be advantageous is a guaranteed header two-wire interface in which reliability information may be included in the header information to allow for more reliable communications between components.

## BRIEF SUMMARY OF THE INVENTION

[0018] The foregoing problems with the prior state of the art are overcome by the principles of the present invention. The principles of the present invention may be implemented in a system that includes a master component and one or more slave components. The master component is configured to communicate with the slave component(s) over a data wire and a clock wire using a guaranteed-header two wire interface. In other words, each byte or word (or other small fixed amount) of transferred data includes its own dedicated header information.

[0019] The master component determines that an operation is to be performed on the slave component, and then begins transmitting the frame to the slave component including an identification of the operation to be performed. The master component then transfers control of the data wire to the slave component. The slave component then transmits a remaining portion of the frame to the master component over the data wire. The frame includes reliability information such as cyclic redundancy checking data or acknowledgement data that the master component may then use to determine whether the operation was successful.

[0020] Additional features and advantages of the invention will be set forth in the description that follows, and in part will be obvious from the description, or may be learned by the practice of the invention. The features and advantages of the invention may be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims. These and other features of the present invention will become more fully apparent from the following description and appended claims, or may be learned by the practice of the invention as set forth hereinafter.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

[0021] In order to describe the manner in which the above-recited and other advantages and features of the invention can be obtained, a more particular description of the invention briefly described above will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments of the invention and are not therefore to be considered to be limiting of its scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

[0022] Figure 1 illustrates an example of a system in which a master component communicates with one or more slave components over a two-wire interface that includes a clock wire and a data wire;

[0023] Figure 2 schematically illustrates a sequential data structure of a frame that defines a guaranteed header two-wire interface in accordance with the principles of the present invention;

[0024] Figure 3A illustrates an example frame in which the operation is to write or read using an extended field, and using Cyclic Redundancy Checking (CRC) and acknowledgements;

[0025] Figure 3B illustrates an example frame in which the operation is to write or read without using an extended field, and using CRC and acknowledgements;

[0026] Figure 3C illustrates an example frame in which the operation is to write or read without using an extended field, and without using CRC and acknowledgements;

[0027] Figure 4 illustrates a flowchart of a method for reliably communicating over a guaranteed header two-wire interface in accordance with the principles of the present invention;

[0028] Figure 5 illustrates a schematic diagram of a laser transmitter/receiver that represents one of many systems in which the principles of the present invention may be employed;

[0029] Figure 6 illustrates a digital portion of the control chip illustrated in Figure 5, the digital portion including a memory that includes the bit-wise accessible portion; and

[0030] Figure 7 illustrates a guaranteed header two-wire interface frame in accordance with the prior art.

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## **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

[0031] The principles of the present invention relate to a guaranteed header two-wire interface that includes reliability information in the header information of the frame. The reliability information is not in the data portion of the frame, and thus there need not be a data evaluation logic component that specifically recognizes the reliability information. The reliability information allows for safer communications using guaranteed header two-wire interfaces.

[0032] Turning to the drawings, Figure 1 illustrates an electronic or computing system 100 in which a master component 110 is in communication with one or more slave components 120. The slave component(s) 120 include a slave component 121 amongst potentially any number of other slave components as represented by the vertical ellipses 122. The master component 110 communicates with any of the slave component(s) 120 over two wires including a clock wire 131 and a data wire 132.

[0033] The master component 110 is referred to as a “master” component because it asserts the clock signal on the clock wire 131 to thereby control the timing of each of the slave component(s) 120. In addition, the master component 110 identifies the operation to be performed by asserting signals on the data wire 132. The slave component(s) 120 are referred to as “slave” components since their timing is controlled by the master component 110, and since they are configured to comply with operations designated by the master component 110. When the master component 110 is to initiate an operation, the master component asserts the clock signal on the clock wire 131, and begins assertion of the frame on the data wire 132. Depending on the type of operation, the slave component 120 that is communicated with may be granted control of the data wire 132 to thereby communicate frame data on the data wire 132. In the following description, the slave component 120 that

is communicated with will often be referred to as the slave component 121 although the master component 110 may elect to communicate with any of the slave component(s) 120.

[0034] Figure 2 illustrates a schematic diagram of a data structure 200 of a frame of a guaranteed header two-wire interface in accordance with the principles of the present invention. The frame 200 includes a preamble field 201, a frame start field 202, an operation field 203, a device identifier field 204, an optional extended field 205, a basic address field 206, a first bus turnaround field 207, and optional bus hold field 208, a data field 209, an optional Cyclic Redundancy Checking (CRC) field 210, a second bus turnaround field 211, an optional acknowledgement field 212, an optional error status field 213, and a frame end field 214. As will be explained in further detail below, the frame 200 is designed so that within any component's turn for control of the data wire, there is a guaranteed zero interspersed more frequently than the length of the preamble.

[0035] The bus turnaround fields allow for optional transfer of data wire control between the master component 110 and the slave component 121. Accordingly, the master component may be providing some of the frame, while the slave component may be providing other portions of the frame. Note that while a specific ordering of fields is shown in Figure 2, there is considerable flexibility as to the ordering of the fields without adversely affecting the functionality of the frame 200 as will be apparent to those of ordinary skill in the art after having reviewed this description.

[0036] Figures 3A, 3B and 3C show specific embodiments of the frame 200. Some of the optional fields are included or excluded depending on the operation being performed. Figure 3A illustrates an example frame in which the operation is to write or read using an extended field, and using Cyclic Redundancy Checking (CRC) and acknowledgements. Figure 3B illustrates an example frame in which the operation is to write or read without

using an extended field, and using CRC and acknowledgements. Figure 3C illustrates an example frame in which the operation is to write or read without using an extended field, and without using CRC and acknowledgements.

[0037] Since Figure 3A illustrates the most inclusive frame example, the various fields of the frame will be described in most detail with respect to Figure 3A. The frame of Figure 3A includes 75 bits corresponding to bits 74:0, regardless of whether the operation is a read operation as specified in line 301A or a write operation as specified in line 304A.

[0038] Line 302A illustrates an asterix at time increments when the master component 110 is in control of the data wire 132 during a read operation, and otherwise contains a period. “MOE” at the beginning of the line stands for “Master data Output Enable”. Line 303A illustrates an asterix at time increments when the slave component 121 is in control of the data wire 132 during a read operation, and otherwise contains a period. “SOE” at the beginning of the line stands for “Slave data Output Enable”.

[0039] Similarly, line 305A illustrates an asterix at time increments when the master component 110 is in control of the data wire 132 during a write operation, and otherwise contains a period. Furthermore, line 306A illustrates an asterix at time increments when the slave component 121 is in control of the data wire 132 during a write operation, and otherwise contains a period. Lines 307A and 308A will be explained further below.

[0040] The frame begins with a preamble as represented in Figure 3A by the 15 bits 74:60. This preamble is an example of the preamble field 201 of Figure 2. The data wire 132 is left in a high impedance state. Absent any assertion on the data wire 132 by master component 110 or any of the slave component(s) 120, the data wire 132 is held to a logical one by a weak pull-up resistor. For example, referring to Figure 1, if the supply voltage 141 were a high supply voltage, the resistor 142 would be the pull-up resistor.

[0041] When the master component 110 determines that a communication is to be made with slave component 121, the master component 110 generates a clock signal on the clock wire 131. At the same time, each clock cycle, the master component 110 monitors the data wire 132 for fifteen consecutive ones. The high impedance data wire 132 does allow for proper assertion of data on the data wire despite the presence of the weak pull-up resistor.

[0042] If the master component 110 is not asserting anything on the data wire 132 during the preamble phase, then the data wire 132 should carry a logical one if none of the slave components is transmitting the remainder of a prior frame on the data wire 132. Alternatively, even if the master component 110 may be asserting a logical one on the data wire during at least some of the preamble, then the data wire 132 should still be carrying the logical one during the preamble phase assuming that none of the slave components is transmitting on the data wire 132 at that time. On the other hand, the frame is designed such that neither a master nor a slave transmits more than fifteen consecutive logical ones in a row when transmitting none-preamble portions of the frame.

[0043] Given the above, if the master component 110 detects a logical zero on the data wire 132 while monitoring the data wire 132 during the preamble phase of the frame, then a slave component is likely communicating on the data wire 132. Whether or not logical zeros are detected, the master component 110 will wait until there are fifteen cycles of logical ones on the data wire 132 before continuing with the frame. Due to the interspersed guaranteed zeros within the frame design, it is then that the master component 110 may safely transmit on the data wire 132 with little risk that one of the slave component(s) is also communicating on the data wire 132.

[0044] Accordingly, even if there is an error in synchronization between the master component 110 and the slave component 121, synchronization is reacquired as the master component 110 waits for the slave component 121 to complete its use of the data wire 132 before proceeding. The slave component 121 also monitors the data wire 132 for fifteen consecutive ones. Accordingly, when the slave component 121 encounters fifteen consecutive ones, the slave component 121 awaits the rest of the transmission. Accordingly, since the slave component 121 is not using the data wire 132 at the time of the preamble regardless of whether the slave component 121 had previously lost synchronization with the master component 110, the slave component should be listening for the preamble at the preamble phase of the frame. Accordingly, the slave component 121 reacquires synchronization with the master component 110.

[0045] Therefore, the preamble is significantly shortened while further retaining error recovery from loss of synchronization. Furthermore, since the data wire 132 is biased high due to the weak pull-up resistor, the master component need not assert any data on the data wire 132 during the preamble phase, thereby reducing power requirements. Note that the preamble could be a sequence of logical zeros (instead of ones) with rest of the frame having interspersed guaranteed ones (instead of zeros), and with the resistor being a weak pull-down resistor, with the same effect. For example, referring to Figure 1, if the supply voltage 141 were a low supply voltage, the resistor 142 would be the pull-down resistor. In the case of a pull-down resistor, the preamble and the bit 01 would all be logical zeros rather than logical ones as shown.

[0046] Once the preamble phase is completed (i.e., the master component 110 has detected at least fifteen consecutive binary ones on the data wire 132), the master component 110 asserts a logical one on the data wire as represented by bit 59. This turns on the output

enable for the master component 110, and maintains the data wire 132 at the logical one for one more cycle.

[0047] The master component 110 then transmits two start of frame bits 58:57 which are guaranteed logical zeros. These start of frame bits are an example of the start of frame field 202 of Figure 2. After the preamble phase is complete, the slave component(s) are listening for these logical zeros. When they arrive, the slave component(s) understand that the two logical zeros correspond to the start of the rest of the frame, thereby attaining synchronization. Two logical zeros are provided in order to provide sufficient statistical probability that the two logical zeros do indeed represent the start of a frame.

[0048] The master component 110 then transmits three operation code bits 56:54. These operation code bits are an example of the operation field 203 of Figure 2. The three operation code bits would normally permit eight unique operations to be identified. However, in order to guarantee at least one logical zero in this operation code, the number of operations represented by the three bits is six, with the other two permutations of the operation code being reserved. In the illustrated example, bit sequences 011 and 111 are reserved.

[0049] In the example, operations bits 000 mean a write operation without using an extended field (explained further below), but with CRC checking and acknowledgements. A frame for this operation is shown in line 304B of Figure 3B (see bits 47:45 of line 304B).

[0050] Operation bits 001 mean a write operation using an extended field, and with CRC checking and acknowledgments. A frame for this operation is shown in line 304A of Figure 3A (see bits 56:54 of line 304A).

[0051] Operation bits 010 mean a write operation without using an extended field, and without CRC checking and acknowledgments. A frame for this operation is shown in line 304C of Figure 3C (see bits 35:33 of line 304C).

[0052] Operations bits 100 mean a read operation without using an extended field, but with CRC checking and acknowledgements. A frame for this operation is shown in line 301B of Figure 3B (see bits 47:45 of line 301B).

[0053] Operation bits 101 mean a read operation using an extended field, and with CRC checking and acknowledgments. A frame for this operation is shown in line 301A of Figure 3A (see bits 56:54 of line 301A).

[0054] Operation bits 110 mean a read operation without using an extended field, and without CRC checking and acknowledgments. A frame for this operation is shown in line 301C of Figure 3C (see bits 35:33 of line 301C).

[0055] Note how the structure of the frame differs depending on the operation. Accordingly, the master component 110 controls which frame structure is to be used by controlling the operation code. Upon reading the operation code, the slave component is configured to expect the frame structure corresponding to the operation code. Accordingly, the master component 110 may dynamically adjust the frame structure as needed. In times when bandwidth is more of a concern, the shorter and less reliable frame structure (e.g., Figure 3C) may be used. In times when reliability is more of a concern, the longer and more reliable frames structure (e.g., Figures 3A and 3B) may be used. When further bits are needed for any reason, the frame with the extended field (e.g., Figure 3A) may be used. When these further bits are not needed, the frames without the extended field (e.g., Figures 3B and 3C) may be used.

[0056] Referring back to Figure 3A, after the master component 110 transmits the operation code (i.e., bits 56:54), the master component 110 transmits a three bit device identifier corresponding to bits 53:51. These device identifier bits are an example of the device identifier field 204 of Figure 2. The device identifier identifies which slave component of the slave component(s) 120 that the master component 110 is to communicate with. Since three bits are used for the device identifier in this embodiment, there may be up to eight slave components in this embodiment (or seven slave components if the master component is to also have an address for self-diagnostic purposes).

[0057] Until the time that the device identifier bits are provided, each of the slave component(s) 120 was monitoring the communications over the data wire 132. However, upon receiving the device identifier bits, the slave component 121 may identify itself as corresponding to the device identifier. The other slave components, if any, may ignore the rest of the frame. Even though the other slave components ignore the rest of the frame, the other slave components may immediately continue monitoring the data wire 132 for another preamble indicative of another frame being transmitted. Alternatively, the other slave component may initiate such monitoring after clock signals are once again asserted on the clock wire 131 indicating that the next frame is about to begin.

[0058] After the master component 110 asserts the device identifier bits 53:51 on the data wire 132, the master component asserts eight bits 50:43 that correspond to an extended field. These extended bits are an example of the extended field 205 of Figure 2. In the case of Figure 3A, the operation code causes the slave component to expect these extended bits. The master component then transmits a guaranteed logical zero as bit 42 thereby ensuring that fifteen consecutive logical ones on the data wire 132 means that a frame is in the

preamble phase to thereby support the above-described synchronization recovery mechanism.

[0059] The extended field may include any extended bits that are useful so long as the meaning of the bits is commonly recognized by both communicating components. For example, some or all of the extended field may represent an extended address for use when communicating with slave components having larger address spaces. Alternatively or in addition, some or all of the extended field may represent an extended operation code where more further operation types are desired.

[0060] The master component 110 then asserts eight bits 41:34 that correspond to the basic address. These eight bits 41:34 are an example of the basic address field 206 of Figure 2. If all of the extended field represents an extended address, the slave component 121 may use all of the sixteen bits 50:43 and 41:34 to properly identify the address space that applies to the operation.

[0061] The next bit 33 in the frame is a first turnaround bit and represents an example of the first turnaround field 207 of Figure 2. The turnaround bits are somewhat unique in that they allow for optional exchange of control of the data wire 132 between the master component 110 and the slave component 121.

[0062] In the case of a write operation, the first turnaround bit 33 is a logical zero, indicating that control is to stay for the time being with the master component. Accordingly, referring to line 305A of Figure 3A, the master component 110 retains control of the data wire through the turnaround bit 33; and referring to line 306A of Figure 3A, the slave component 121 does not gain control of the data wire through the turnaround bit 33. This retaining of control is appropriate since the master component 110 is the one that is

providing that data that is the subject of a write operation initiated by the master component 110.

[0063] On the other hand, in the case of a read operation, the first turnaround bit 33 is a high-z, meaning that the data wire 132 is permitted to float at its high impedance state in which none of the master component 110 or slave component 121 is actively asserting bits on the data wire 132. This represents that control of the data wire has passed to the slave component (see lines 302A and 303A of Figure 3A). This transfer of control is appropriate since the slave component 121 is the one that is providing that data that is the subject of a read operation initiated by the master component 110.

[0064] In the case of a read operation, the slave component 121 then has the opportunity to pause the frame in cases in which the slave component 121 is not ready to continue at this stage. The slave component asserts the bus hold bit 32 to a logical zero if it is not ready to continue. When ready to continue, the slave component 121 asserts a logical one if it is ready to proceed thereby given the master component 110 notice that the slave component is ready to continue. This provides the slave component 121 with an option to pause the frame when the slave component is not ready to continue for the time being. An additional pausing option available to the slave component is described below with respect to the acknowledgement bit. In the case of a write operation, the bus hold bit 32 is a guaranteed logical one. The bus hold bit 32 is an example of the bus hold field 208 of Figure 2.

[0065] In the case of a read operation, after the slave component 121 transmits the bit hold bit 32, the slave component 121 transmits the eight most significant bits followed by a guaranteed zero bit. In the case of a write operation, after the master component 110 transmits the bit hold bit 32, the master component 110 transmits the eight most significant

bits followed by the guaranteed zero bit. In either case, the eight most significant bits are represented by bits 31:24, and the following guaranteed zero bit is represented by bit 23.

[0066] In the case of a read operation, after the slave component 121 transmits the guaranteed zero bit 23, the slave component 121 transmits the eight least significant bits followed by another guaranteed zero bit. In the case of a write operation, after the master component 110 transmits the guaranteed zero bit 23, the master component 110 transmits the eight least significant bits followed by the other guaranteed zero bit. In either case, the eight least significant bits are represented by bits 22:15, while the other guaranteed zero bit is represented by bit 14. The combination of the data bits 31:24 and 22:15 are an example of the data field 209 of Figure 2.

[0067] In the case of a read operation, after the slave component 121 transmits the guaranteed zero bit 14, the slave component 121 transmits eight bits of Cyclic Redundancy Checking (CRC) data corresponding to bits 13:06. The CRC bits are one example of the CRC field 210 of Figure 2. Using all the bits after the start of frame bits 58:57 and prior to the CRC bits 13:06, both the master component 110 and the slave component 121 calculate CRC data as shown in line 307A. When the master component 110 receives the CRC bits 13:06 back from the slave component 121, the master component 110 then compares the CRC information generated by both the master component 110 and the slave component 121 as represented by line 308A. If there is a mismatch, then there has likely been an error in transmission, and the master component may begin the frame again after the current frame is ended.

[0068] In the case of a write operation, after the master component 110 transmits the guaranteed zero bit 14, the master component 110 transmits the CRC bits 13:06. Once again, both the master component 110 and the slave component 121 calculate their CRC

data. When the slave component 121 receives the CRC bits 13:06 from the master component 110, the slave component 121 then compares the CRC information generated by both the master component 110 and the slave component 121. If there is a mismatch, then there has likely been an error in transmission, and the master component 110 may begin the frame again after the current frame is ended after the master component 110 has been notified of the error. In some cases, an erroneous write operation may have catastrophic (or at least harmful) effects. For example, if the erroneous write operation was for setting a laser bias current, the laser strength could be too strong such that signal distortion occurs. Accordingly, reliable communications is important in such circumstances. The slave component 121 may elect to suppress a write operation when such an error is detected.

**[0069]** After the CRC bits 13:06, there is a second turnaround bit 05. This second turnaround bit is an example of the second turnaround field 211 of Figure 2. This turnaround operation allows control of the data wire 132 to be given to the slave component 121 if control is not there already. This allows the slave component 121 to give reliability information back to the master component 110.

**[0070]** In the case of a read operation, control of the data wire 132 has already been passed to the slave component 121 using the first turnaround bit. Accordingly, this second turnaround bit is a logical zero indicating no change in control of the data wire 132. On the other hand, in the case of a write operation, control of the data wire 132 was not previously given to the slave component 121 using the first turnaround bit. Accordingly, the data wire 132 is allowed to float at its high impedance state indicating a transfer of control of the data wire 132 to the slave component 121. Accordingly, after the second turnaround bit 05, the slave component 121 has control of the data wire 110 regardless of whether the operation is a read operation or a write operation.

[0071] After the second turnaround bit 05, the slave component asserts an acknowledgment bit 04, which is an example of the acknowledgement field 212 of Figure 2. This acknowledgement bit may represent whether or not the operation was successful. In this case, a logical one means successful completion of the operation. Had the slave component 121 been too busy to respond to the master component 110, the slave component may assert a logical zero for the acknowledgement bit 04, thereby forcing the master component 110 to reinitiate the frame. Accordingly, the acknowledgment bit 03, and the bit hold bit 32 provide a way for the slave component 121 to address the situation where it cannot respond to the request (this is true for both reads and writes).

[0072] The slave component 121 then asserts a guaranteed zero bit 03, followed by an error bit 02, which is an example of the error field 213 of Figure 2. The error field may indicate whether or not there was an error in CRC checking and/or a violation of the protocol (e.g., a logical one is detected where a logical zero should occur). In the case of a read operation, the master component will already be in possession of CRC data sufficient to make this determination. However, in the case of a write operation, the slave component 121 is the one that made the comparison of CRC data. Accordingly, it is at this time that the slave component 121 notifies the master component 110 of any mismatch in CRC data. A mismatch would result in the master component 110 reinitiating the frame. The presence of CRC and acknowledgment information in the frame allows for more reliable communication between the master component 110 and the slave component(s) 120.

[0073] The slave component 121 then asserts two end of frame bits 01:00, which indicates the end of the frame. The first bit 01 is a logical one, which forces the data bus immediately to a logical one. In the second bit, the data bus 132 is allowed to float at its high impedance state, ready for the next frame to begin. If the first bit 01 were a logical

zero, it may take some time for the weak pull-up resistor to pull the data wire 132 up to a voltage level that could be interpreted as a logical one. Accordingly, the setting of the first bit 01 at a logical one means that the next frame may begin sooner, thereby improving performance.

[0074] Figure 3B illustrates an example frame in which the operation is to write or read without using an extended field, and using CRC and acknowledgements. The frame of Figure 3B is similar to that described above with respect to Figure 3A, except that the operation is to write or read without using an extended field. Accordingly, bits 50:42 of Figure 3A are absent from Figure 3B and the bits are renumbered accordingly.

[0075] Figure 3C illustrates an example frame in which the operation is to write or read without using an extended field, and without using CRC and acknowledgements. The frame of Figure 3C is similar to that described above with respect to Figure 3A, except that the operation is to write or read without using the extended field. Accordingly, bits 50:42 of Figure 3A are absent from Figure 3B. Furthermore, there is no reliability information within the frame. Hence, bits 13:02 of Figure 3A are absence from Figure 3C. The absence from Figure 3C of bits that are present in Figure 3A warrants the renumber of the remaining bits in Figure 3C.

[0076] Figure 4 illustrates a flowchart of a method 400 for reliably communicating over a guaranteed header two-wire interface in accordance with the principles of the present invention. While some aspects of this method have been described above, more specifics are now provided with respect to the flowchart.

[0077] Some of the acts of the method 400 are performed by the master component as represented in the left column of Figure 4 under the heading “Master Component”. Other

acts of the method 400 are performed by the slave component as represented in the right column of Figure 4 under the heading “Slave Component”.

[0078] The master component determines that an operation is to be performed on the slave component (act 401), and then begins transmitting the frame to the slave component (act 402) including an identification of the operation to be performed. The slave component receives the transferred portion of the frame (act 403). The master component then transfers control of the data wire to the slave component (at 404). Upon receiving the control (act 405), the slave component then transmits a remaining portion of the frame to the master component over the data wire (act 406). The frame includes reliability information such as cyclic redundancy checking data or acknowledgement data that the master component may then use to determine whether the operation was successful (act 407).

[0079] For instance, referred to Figures 3A and 3B, the master component receives cyclic redundancy checking data, acknowledgment data, and error data from the slave component during a read operation. The master component may compare the slave component generated cyclic redundancy data and compare it with its cyclic redundancy data that the master component generated to see if there was an error in transmission. The acknowledgement information indicates whether or not the operation was successful. The error message indicates whether or not there were any errors during the execution of the operation.

[0080] The master component supplies the cyclic redundancy checking data, and receives the acknowledgement and error information during a write operation. The slave component compares the cyclic redundancy checking information supplied by the master component with its own generated cyclic redundancy checking information to determine if there was an error in transmission. The slave component indicates a success or failure of

this comparison in the error information transmitted back to the master component. Accordingly, reliable transmission is accomplished. Having described the basic principles of the present invention, a particular example environment will now be described, although the present invention is not limited by any means to this example environment.

[0081] Figure 5 illustrates a laser transmitter/receiver 500 in which the principles of the present invention may be employed. While the laser transmitter/receiver 500 will be described in some detail, the laser transmitter/receiver 500 is described by way of illustration only, and not by way of restricting the scope of the invention. The principles of the present invention allow for more efficient and accurate calibration of register values important to the operation of the transmitter/receiver 500 (such as laser bias current, laser modulation) to account for temperature, voltage supply, and process fluctuations. This will become increasingly important for faster bit rates transfers. Accordingly, the principles of the present invention are suitable for 1G, 2G, 4G, 10G and higher bandwidth fiber channels. Furthermore, the principles of the present invention may be implemented in laser transmitter/receivers of any form factor such as XFP, SFP and SFF, without restriction.

[0082] The laser transmitter/receiver 500 receives an optical signal from fiber 510A using receiver 501. The receiver 501 transforms the optical signal to an electrical signal and provides that electrical signal to a post-amplifier 502. The post-amplifier 502 amplifies the signal and provides the amplified signal to the host as represented by arrow 502A.

[0083] The laser transmitter/receiver 500 may also receive electrical signals from the host for transmission onto the fiber 510B. Specifically, the laser driver 503 receives the electrical signal as represented by the arrow 503A, and drives the transmitter 504 (i.e., the laser) with signals that cause the transmitter 504 to emit onto the fiber 510B optical signals representative of the information in the electrical signal provided by the host.

[0084] The behavior of the receiver 501, the post-amplifier 502, the laser driver 503, and the transmitter 504 may vary dynamically due to a number of factors. For example, temperature changes, power fluctuations, and feedback conditions may each affect the performance of these components. Accordingly, the laser transmitter/receiver 500 includes a control chip 505, which evaluates temperature and voltage conditions, and receives information from the post-amplifier 502 (as represented by arrow 505A) and from the laser driver 503 (as represented by arrow 505B), which will allow the control chip 505 to counteract the dynamically varying performance, and detect when there is a loss of signal.

[0085] Specifically, the control chip 505 may counteract these changes by adjusting settings on the post-amplifier 502 and/or the laser driver 503 as represented by the arrows 505A and 505B. These settings adjustments are quite intermittent since they are only made when temperature or voltage or other low frequency changes so warrant. Accordingly, the setting adjustments may be made by a guaranteed header two-wire interface of the type described above with respect to Figures 1, 2, and 3A through 3C.

[0086] The control chip 505 has access to a non-volatile memory 506, which in one embodiment, is an Electrically Erasable and Programmable Read Only Memory (EEPROM). Data and clock signals may be provided from the host to the control chip 505 using the serial clock line SCL, and the serial data line SDA. Also data may be provided from the control chip 505 to the host using serial data signal SDA to allow for digital diagnostics and readings of temperature levels, transmit/receiver power levels, and the like.

[0087] The control chip 505 includes both an analog portion 508 and a digital portion. Together, they allow the control chip to implement logic digitally, while still largely interfacing with the rest of the laser transmitter/receiver 500 using analog signals. For example, the analog portion 508 may contain digital to analog converters, and analog to

digital converters, high speed comparators (e.g., for event detection), voltage based reset generators, voltage regulators, voltage references, clock generator, and other analog components.

[0088] Figure 6 illustrates the digital portion 600 of control chip 505 in further detail. For instance, a timer module 602 provides various timing signals used by the digital portion. Such timing signals may include, for example, programmable processor times. The timer module 602 may also act as a watchdog timer.

[0089] Two general-purpose processors 603A and 603B are also included. The processors recognize instructions that follow a particular instruction set, and may perform normal general-purpose operation such as shifting, branching, adding, subtracting, multiplying, dividing, Boolean operations, comparison operations, and the like. In one embodiment, the general-purpose processors 603A and 603B are each a 16-bit processor and may be identically structured.

[0090] A host communications interface 604 is used to communicate with the host using the serial clock line SCL and the serial data line SDA of the laser transmitter/receiver 500. The external device interface 605 is used to communicate with, for example, other modules within the laser transmitter/receiver 500 such as, for example, the post-amplifier 502, the laser driver 503, or the memory 506.

[0091] The memory 606 may be Random Access Memory (RAM). The memory control 607 shares access to the memory 606 amongst each of the processors 603A and 603B and with the host communication interface 604 and the external device interface 605. In one embodiment, the host communication interface 604 includes a serial interface controller 601A, and the external device interface 605 includes a serial interface controller 601B. The two serial interface controllers 601A and 601B may communicate using the two-wire

interface described just above. One serial interface controller (e.g., serial interface controller 601B) being the master component, while the other serial interface controller (e.g., serial interface controller 601A) is a slave component.

**[0092]** An input/output multiplexer 608 multiplexes the various input/output pins of the control chip 505 to the various components within the control chip 505. This enables different components to dynamically assign pins in accordance with the then-existing operational circumstances of the chip. Accordingly, there may be more input\output nodes within the control chip 505 than there are pins available on the control chip 505, thereby reducing the footprint of the control chip 505.

**[0093]** Having described a specific environment with respect to Figures 5 and 6 in which the principles of the present invention described with respect to Figures 1, 2, 3A, 3B, 3C and 4 may be employed, it will be understood that this specific environment is only one of countless architectures in which the principles of the present invention may be employed. As previously stated, the principles of the present invention are not intended to be limited to any particular environment.

**[0094]** The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes, which come within the meaning and range of equivalency of the claims, are to be embraced within their scope.

**[0095]** What is claimed and desired secured by United States Letters Patent is: